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STREAM SURVEYS IN VICINITY OF URANIUM MILLS. III. AREA OF URAVAN, SLICK ROCK, AND GATEWAY, COLORADO - AUGUST 1960

PUBLIC HEALTH SERVICE
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This is a report of one of three short-term field studies carried out in the vicinity of uranium processing mills in western Colorado and eastern Utah during August 1960. These studies were the initial undertaking of the Colorado River Basin Water Quality Control Project and were made for the purpose of determining the pollutional constituents contained in uranium mill discharges and the effects of these discharges on receiving waters in certain specific areas of the Colorado River Basin. The results of the other studies are contained in reports of the Colorado River Basin Project.

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COLORADO RIVER BASIN WATER QUALITY CONTROL PROJECT
Public Health Service

BACKGROUND AND OBJECTIVES

The Colorado River Basin Water Quality Control Project was initiated by the Public Health Service at the request of the water pollution control agencies of the seven Basin states at a conference called by the Surgeon General in Phoenix, Arizona, January 13, 1960, under provisions of section 8, Public Law 660, 84th Congress, the Federal Water Pollution Control Act. The Project is consequently operating under the interstate enforcement provisions of the Act and is directed toward the accomplishment of the following objectives:

1. A determination of the specific pollutants and their concentrations which now exist or which may reasonably be expected to exist in the immediate future resulting from various water uses within the Basin, and the establishment of priorities for developing data on, and securing needed remedial action at the most critical and pressing problem areas.

2. A determination of methods for securing the best possible water quality for multiple water use and the development of a comprehensive plan and program of water quality control for multiple water use within the Basin which can serve as a guide for the conference and to state and Federal agencies having an interest in the prevention and control of water quality degradation.

Under the conference mechanism the official conferees consist of a representative of the Public Health Service and the water pollution control agencies of each of the states involved. The conferee group associated with this enforcement action is as indicated on the cover of this report.

ORGANIZATION

The Project Headquarters office, consisting of engineering and associated professional and clerical personnel, is located in Denver, Colorado. A laboratory for the sanitary analysis of samples collected has been established in Salt Lake City, Utah, and will provide the facility for radiological, bacteriological, biological, and chemical analyses of the various samples collected.

The Project is administratively attached to the Water Supply and Pollution Control program of the Public Health Service, Department of Health, Education, and Welfare, Region VIII, Denver, Colorado. The Water Supply and Pollution Control programs in DHEW Region VII, Dallas, Texas, and DHEW Region IX, San Francisco, California, are also cooperating with the Project, since portions of these regions lie in the Colorado River Basin.

FOREWORD

This study was carried out by the Colorado River Basin Water Quality Control Project with the generous assistance of Public Health Service personnel from other offices. Active in the field conduct of the survey were: J. B. Anderson of PHS Region VII, M. A. Bauer, Jr. of PHS Region VIII, M. W. Lammering of R. A. Taft Sanitary Engineering Center, and P. A. Fichter of the Colorado River Basin Project Laboratory. Chemical and radiological analyses were performed by D. A. Clark and R. K. Jarrell of the Colorado River Basin Project, and C. R. Hirth, B. Smith, and A. E. McSorley of R. A. Taft Sanitary Engineering Center. The report of this study was prepared by J. W. Kittrell of the Colorado River Basin Project. These studies in the vicinity of uranium mills have been carried out under the general supervision of Charles E. Sponagle, Project Director, Colorado River Basin Project.

ACKNOWLEDGMENTS

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For assistance in sampling at uranium mills: A. Lankenau and the staff of Union Carbide Nuclear Co., Uravan, Colorado; and O. J. Malacarne and the staff of Union Carbide Nuclear Co., Slick Rock, Colorado.

For assistance in obtaining flow measurements: R. E. Whiteman and the staff of U. S. Geological Survey, Grand Junction, Colorado.

For permission to use space and facilities: R. McDonald, Colorado Department of Game and Fish, Durango, Colorado; F. Willers and W. Kay, Water Treatment Plant, Grand Junction, Colorado; and D. A. Holaday, Occupational Health Field Station, PHS.

For technical consultation and assistance in the planning and execution of the survey: D. E. Rushing of the Colorado River Basin Project Laboratory and E. C. Tsivoglou of R. A. Taft Sanitary Engineering Center, PHS.

STREAM SURVEYS IN VICINITY OF URANIUM MILLS

III. AREA OF URAVAN, SLICK ROCK, AND GATEWAY, COLORADO - AUGUST 1960

INTRODUCTION

Purpose

This is a report of one of three short-term field studies carried out in the vicinity of uranium processing mills in western Colorado and eastern Utah during August 1960. These studies were the initial undertaking of the Colorado River Basin Water Quality Control Project and were made for the purpose of determining the pollutional constituents contained in uranium mill discharges and the effects of these discharges on receiving waters in certain specific areas of the Colorado River Basin. The results of the other studies are contained in reports of the Colorado River Basin Project (1)(2).

General Description of the Area and Mill Processes

Both the Dolores and San Miguel Rivers rise in the San Juan Mountains of southwestern Colorado. The San Miguel flows generally northwest some 80 miles from its headwaters to its confluence with the Dolores. The Dolores takes a more circuitous route, flowing southwest, northwest, and finally north for about 130 miles before the confluence. From this point, it flows north and northwest 67 miles to its meeting with the Colorado River south of Cisco, Utah. Both rivers in the upper reaches flow through high mountain valleys which gradually narrow into canyons in the downstream reaches. For much of the 60 miles between Slick Rock and its meeting with the San Miguel River, the Dolores River flows through canyons which make access difficult to impossible. Below the confluence its course meanders through a series of valleys and canyons with varying degrees of accessibility. Figure I indicates the immediate area in which this survey was conducted. River mileages for pertinent locations in the area are given in Table I along with population figures. The mouth of the Dolores River is in Utah at Colorado River mile 1024, 36 miles above Moab, Utah, the first community downstream from the mouth.

In general appearance, the San Miguel River in the survey area above Uravan might be considered as a typical mountain stream, swift, shallow, cool, and clear. Below Uravan its color ranged from red-brown to yellow-brown. By contrast, the Dolores River from Slick Rock to the confluence of the two rivers was almost dry for part of the survey period. Public Health Service engineers making the survey felt that a large portion of the flow at Slick Rock was in underground strata. Below the confluence, the channel widens out, average water velocity is lower, and the stream is warmed somewhat in its journey to Gateway, Colorado.

Both mills presently operating in the area under study are owned by Union Carbide Nuclear Company. The Uravan mill extracts uranium and vanadium from feed ores. Uranium recovery is by an acid leach and ion exchange process.

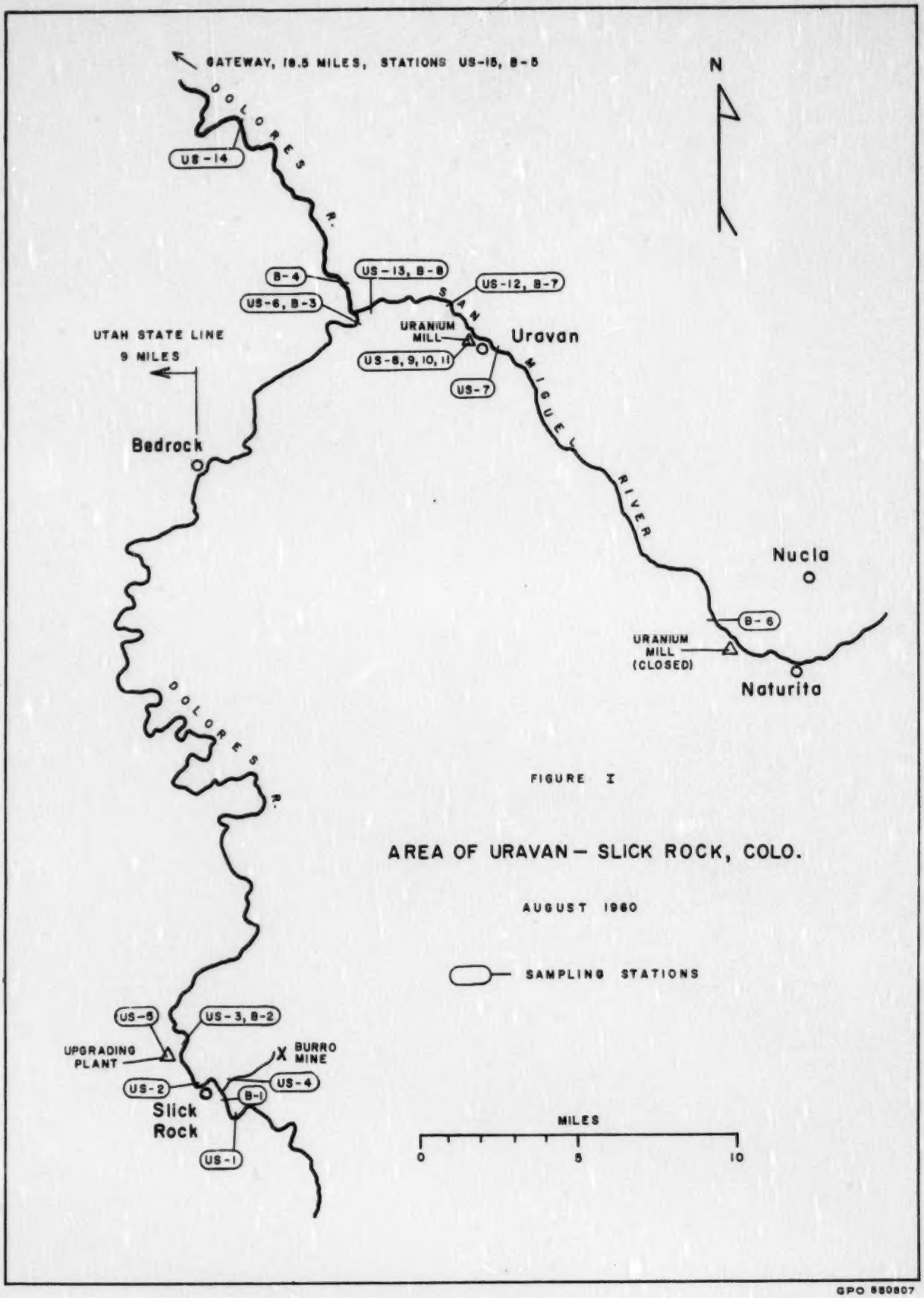

FIGURE I

AREA OF URAVAN — SLICK ROCK, COLO.

AUGUST 1960

GPO 850807

TABLE I
RIVER MILEAGES[a]

Location	River Mileage	Population
Gateway	34	110
Sampling Station US-14	57	-
Confluence of Dolores and San Miguel Rivers	67	-
Uravan, mill and town	67-5	1005
VCA uranium mill, Naturita	67-18	-
Naturita	67-22	979
Bedrock	79	20
Slick Rock, mill and mill community	127	200
Slick Rock, Burro Mine	130	-

[a]Mile zero is taken as the mouth of the Dolores River. A single figure for mileage indicates location on the Dolores River. A two figure mileage indicates location on the San Miguel River and gives first, the distance between the confluence of the Dolores and San Miguel Rivers and mouth of the Dolores, and second, the distance from the particular location to the confluence.

- - - -

The liquor from uranium ion exchange is ammonia treated to precipitate vanadium values. At the time of the survey, three separate effluents were being discharged to the San Miguel River. (1) The liquor stripped of uranium and vanadium values, constituting about 55 percent of the total daily discharge, was being treated to precipitate dissolved radium by the addition of barium salts. It then passed through two small tailings ponds before being discharged to the river. (2) Stripped ion exchange eluate, "Yellow cake tails," was being discharged through one small tailings pond into the river. (3) Vanadium precipitation tailings liquor, "red cake tails," was discharged directly to the river. Also, a ditch traversing the hillside above the mill collected seepage from the acid leach area atop the hill and discharged into the river upstream from the effluents.

The Slick Rock mill concentrates uranium ores by a particle size separation, acid leach process. Leached solids, consisting of the largest particles passing through the process, are sluiced to a tailings pile some 100 yards from the Dolores River with liquor from which the uranium values have been removed. This sluice water is the only liquid mill effluent. It seeps down through the tailings pile and into land lying adjacent to the Dolores River. Numerous small seeps were seen coming from the river bank close by the tailings pile. Operation of this plant was suspended in January 1962.

WATER USES AND WASTE DISCHARGES

Slick Rock Area

The Burro Mine produces some waste water from underground sources which enters the Dolores River just below the mine. A number of dwellings lie in the

bottom lands upstream from this mine. The old, nearly abandoned mining community of Slick Rock lies just downstream from the mine; a few people were living there at the time of the survey. Since no wells are known to be in those immediate areas, there is a possibility that some occupants use river water for domestic purposes. Below the mine but above the mill, a farm irrigates 20 to 25 acres of alfalfa. The farmer has 20 to 30 head of cattle which use the river as a source of drinking water and are partially fed on the alfalfa.

Drinking water for the mill and trailer community is taken from a series of 5 deep wells owned and operated by Union Carbide Nuclear Company. This well water is stored in a large man-made cavern in the hill above the mill and is chlorinated before distribution. It is reported that the main domestic well is located on the edge of a draw and is susceptible to flooding at times of high water. Trailer community sewage is treated in a septic tank with subsurface disposal field.

Process water for the Slick Rock mill is taken from a pool behind a small rock dam in the Dolores River and is supplemented by wells in times of extremely low flow. Cattle graze in the area below the mill and are watered from one of the company wells. Horses imported during the time of the survey for employee recreation refused to drink the river water, possibly due to its high saline content.

Present knowledge indicates individual facilities for water and sewage serve the 20 people at Bedrock.

Uravan Area

Naturita draws its domestic water supply from the San Miguel River; treatment is by settling and chlorination. A rated aeration sewage treatment plant has been completed recently and put into operation.

Domestic water for the Uravan community is taken from company-owned wells on the north side of the San Miguel River and given conventional treatment before use. This source also furnishes water for the community swimming pool. Process water for the mill is taken from a diversion channel supplied by a small dam just upstream from the town. Before the rain during the second half of the survey, the entire flow of the San Miguel River was diverted through this channel. Brine used in the ion exchange process is pumped from a well in Paradox Valley, just east of the Dolores River. Community sewage is treated in many septic tanks with subsurface disposal. There is no apparent discharge to the river from these.

A ranch below Uravan irrigates about 70 acres with water taken from the San Miguel River above the Uravan mill diversion dam.

Dolores River below Mouth of San Miguel River

A ranch northwest of Uravan (near Station US-14) irrigates approximately 20 acres of alfalfa. At the time of this survey, the field was being irrigated from a source other than the Dolores River, reportedly because of its high salt

content. This primary source is used whenever water is available. Otherwise the Dolores River is used, but only as a last resort. The owner of the ranch indicated that his cattle have at times drunk from the river.

At Gateway, another ranch irrigates approximately 200 acres of pasture crops with river water. A few acres of grain and a small orchard are also irrigated. The river is used during high spring flows when salt concentrations are low; then the owner turns to a supplemental source during the summertime. There is a community "swimming hole" some 5 miles above Gateway which was in use almost daily during the survey. The channel here is 40-45 feet wide and deep enough for diving from a homemade board some 10 feet above the surface. There is a picnic area here also.

Gateway has individual water supplies and a community septic tank. A typical sewage odor was noted at the Gateway sampling station several times during this survey.

CONDUCT OF THE SURVEY

The survey was conducted in the area of Uravan, Slick Rock, and Gateway, Colorado during the period August 17-28, 1960. Water samples were filtered daily and composited by cycles in the laboratory at the Grand Junction Water Treatment Plant. Bioassays were performed at the Colorado State Fish Hatchery, Durango, Colorado.

Sampling Stations

Two sets of sampling stations were used, one for water samples, the other for bottom fauna. Sampling stations are shown in Figure I; stream and effluent sampling stations are designated with the code "US", bottom organism stations are designated with the code "B". A detailed description of the stations follows below and gives locations of corresponding stations.

TABLE II
DESCRIPTION OF SAMPLING STATIONS

Station	Location and Description
US-1	Dolores River, 4.5 river miles upstream from Slick Rock plant, and approximately 0.2 mile up from Colorado Highway 80 bridge. Stream bottom rocky and covered with mud. Stream bed very nearly dry many days; main flow in subsurface aquifer.
B-1	Dolores River, 4.2 river miles upstream from Slick Rock plant. Downstream from Colorado Highway 80 bridge.
US-4	Effluent from Burro Mine, 3.3 miles above plant. Sample collected at end of pipe carrying effluent from mine.

Station	Location and Description
US-2	Dolores River, 1.3 miles above Slick Rock plant, below Burro Mine. Stream depth rarely more than 6 inches. Bottom covered with large, mud-coated rocks. Mud deposits at side of channel. Flow interrupted during survey.
US-5	Seepage from Slick Rock plant tailings pile. Sample taken from a flume and weir arrangement set into the river bank at the edge of the seep area.
US-3	Dolores River, 0.9 miles downstream from Slick Rock plant. Bottom similar to US-2, less muddy. Salt deposits on exposed rocks. Flow channel 7' to 8' wide, 2" deep in riffle area. Flow interrupted during survey. Corresponds to Station B-2.
US-6	Dolores River 1/4 mile above confluence with San Miguel River. Flow in two channels most of time; one shallow, rapid, the other slightly deeper, slower. Extensive salt deposits on exposed rocks, stream very turbid. Bottom rocky with thin film of mud coating. Corresponds to Station B-3.
B-6	San Miguel River near Naturita, 1/2 mile below VCA mill, approximately river mile 18.
US-7	San Miguel River at Colorado Highway 141 bridge, 0.9 miles upstream from Uravan mill. Stream width generally 20-25 ft., depth 2-1/2 ft., clear and swift. Bottom rocky with little mud, but algae growth present.
US-11	Ditch drainage from mesa above Uravan mill. Enters river below mill diversion channel.
US-9	Effluent from tailings pond farthest upstream, uranium and vanadium stripped liquor. "Plant 5 overflow."
US-10	Effluent from second tailings pond in series, stripped ion exchange eluate. "Yellow cake press filtrate."
US-8	Direct discharge to San Miguel River, vanadium precipitation tailings liquor. "Red cake tails."
US-12	San Miguel River, 1.6 miles below Uravan mill. Stream red to red-brown, due to presence of

Station	Location and Description
	large floc particles. Depth generally 1-1/2 ft., width 30 to 40 ft. Bottom rocks covered with red-gray film. Corresponds to Station B-7.
US-13	San Miguel River just above mouth. Width 24-30 ft., depth 1-1/2 ft. Stream swift with general appearance and bottom as at Station 12, except coloration not as intense as at Station US-12. Corresponds to Station B-8.
B-4	Dolores River, 4.7 river miles below confluence of Dolores and San Miguel Rivers.
US-14	Dolores River, 12.2 river miles below confluence, 21.4 miles above Gateway, at bridge, Colorado Highway 141. Two channels, rocky bottom. Wider channel had slower velocity, greater depth, gray-brown mud bottom. Narrow channel had 6" to 1' depth, swifter velocity, gray-green slime-mud bottom combination, less turbid water.
US-15	Dolores River, at Gateway, Colorado. Riffles just downstream of Highway 141 bridge. Stream wide, 2-1/2 ft. deep, very turbid after rain. Bottom rocks covered with light algae growth and slime. Corresponds to Station B-5.

SAMPLE COLLECTION AND PROCESSING

Slick Rock Area

Two quart river samples and one quart effluent samples for chemical and radiological analysis were taken daily, August 17-28. The sampling period was divided into a 5-day composite cycle (I), August 17-21, and a 7-day cycle (II), August 22-28. On days where there was no flow at a particular station, no sample was collected. Two quarts of Burro Mine drainage were collected daily for the first cycle of which one was filtered by the Slick Rock plant laboratory through Whatman #2 paper. During cycle I, the Slick Rock plant seepage was sampled by a daily grab; during the second cycle an automatic sampler took a sample once an hour which was composited and collected each day.

Uravan Area

River and effluent sampleswere the same size as in the Slick Rock area. All four effluent samples at Uravan were taken daily from 24-hour composites by company-owned splitter box samplers. Compositing periods were the same as in the Slick Rock area.

Other Samples

One pint sediment samples for radiological analysis were taken at each

river station in the survey area once each cycle. All cycle II sediment samples were taken after the thundershowers in the area on August 22 and 23.

Samples for bioassay were taken at each effluent stationdaily and field composited in such volume as to give 1 gallon composites at the end of a sampling period.

The sampling of biological life was done primarily by means of a screen. The screen was copper, 36 x 42 inches, 18 wires per inch, supported with wood on the sides and a steel band along the bottom edge. Organisms were collected from an area of 1 square yard immediately upstream from the screen by picking up rocks and wiping them off in the water so the current would carry them onto the screen. After the screen was removed from the water, the organisms were picked from the screen, placed in glass vials, and preserved with formalin. They were identified, counted, and weighed at a later time.

Processing

As previously mentioned, bioassay samples were field composited preparatory to shipment. River and effluent samples were filtered through a 0.45μ pore diameter membrane filter within 2 days after collection and composited for shipment to the point of analysis at the end of each cycle.

HYDROLOGY

Stream flow data were obtained by two methods. At several of the sampling stations, staff gages, installed and rated by the U.S. Geological Survey, were read daily at the time of sample collection. On the Dolores River, gages were located so as to give flows corresponding to the stations above Burro Mine, below Slick Rock plant, above the confluence, and at Gateway. A gage was also located on the San Miguel River just above its mouth. The U.S. Geological Survey has a water stage recorder located on the San Miguel less than 1 mile above Uravan. Unpublished data from this recorder were furnished; these flows may be considered representative at the station just below Uravan as well as above town. Table III gives measured flows during the survey period. There was a steady general rain downstream from Slick Rock early on the morning of August 22 followed by a short intense rain in the vicinity of the confluence of the Dolores and San Miguel Rivers early in the afternoon of the 22nd. Early on the morning of the 23rd, there was a heavy thunderstorm in the Uravan area. On the 23rd, hourly flow data for the San Miguel River at Uravan recorded 35 cfs at the beginning of the day, 50 cfs at the end, with a peak of 622 cfs during the day as a result of heavy runoff. There was not enough rain above Slick Rock to affect river flows there.

Comparisons with published information indicate that the survey period was one of the driest on record. Published data for the two pertinent stations are summarized in Table IV; Figure II is a hydrograph for the San Miguel at Uravan for calendar years 1959 and 1960.

TABLE III (a)
FLOW DATA

Date	Dolores R. above Burro Mine US-1	Dolores R. below Slick Rock US-3	Dolores R. above confluence US-6	San Miguel River above and below Uravan US-12	San Miguel River above mouth US-13	Dolores R. at Gateway US-15
8/15	0.29	0.22	1.7	43	43.0	46
8/16	0.05	0.17	1.2	39	42.0	-
8/17	0.01	0.19	0.8	39	42.0	38
8/18	0.01	0.22	1.0	39	35.8	34
8/19	0.0	-	1.0	44	51.9	37
8/20	0.0	-	1.0	36	32.0	43
8/21	0.0	-	1.0	32	33.8	36
Cycle I) Avg.)	0.05	0.20	1.1	39	40	39
8/22	0.0	-	1.0	30	26.4	33
8/23	0.0	-	82.5	153	153	34
8/24	0.16	-	36.1	49	53.0	162
8/25	0.04	0.22	17.5	47	55.3	79
8/26	0.01	0.24	9.5	38	42.0	61
8/27	0.01	0.22	7.0	34	32.0	41
8/28	0.0	0.19	7.5	31	33.8	36
Cycle II) Avg.)	0.03	0.22	23	54	56	64

(a) All flows in cfs.

TABLE IV
RECORDED FLOWS AT SURVEY STATIONS, cfs

	San Miguel R. at Uravan	Dolores R. at Gateway
Period of Record	8/54-9/60	10/36-12/54
Mean Annual Flow	357	938
Mean August Flow	174	297
Lowest Mean August Flow	66 (1956)	72 (1950)
Highest Mean August Flow	592 (1957)	597 (1947)
Flow, 8/15/60 - 8/21/60	39	39
Flow, 8/22/60 - 8/29/60	54	64

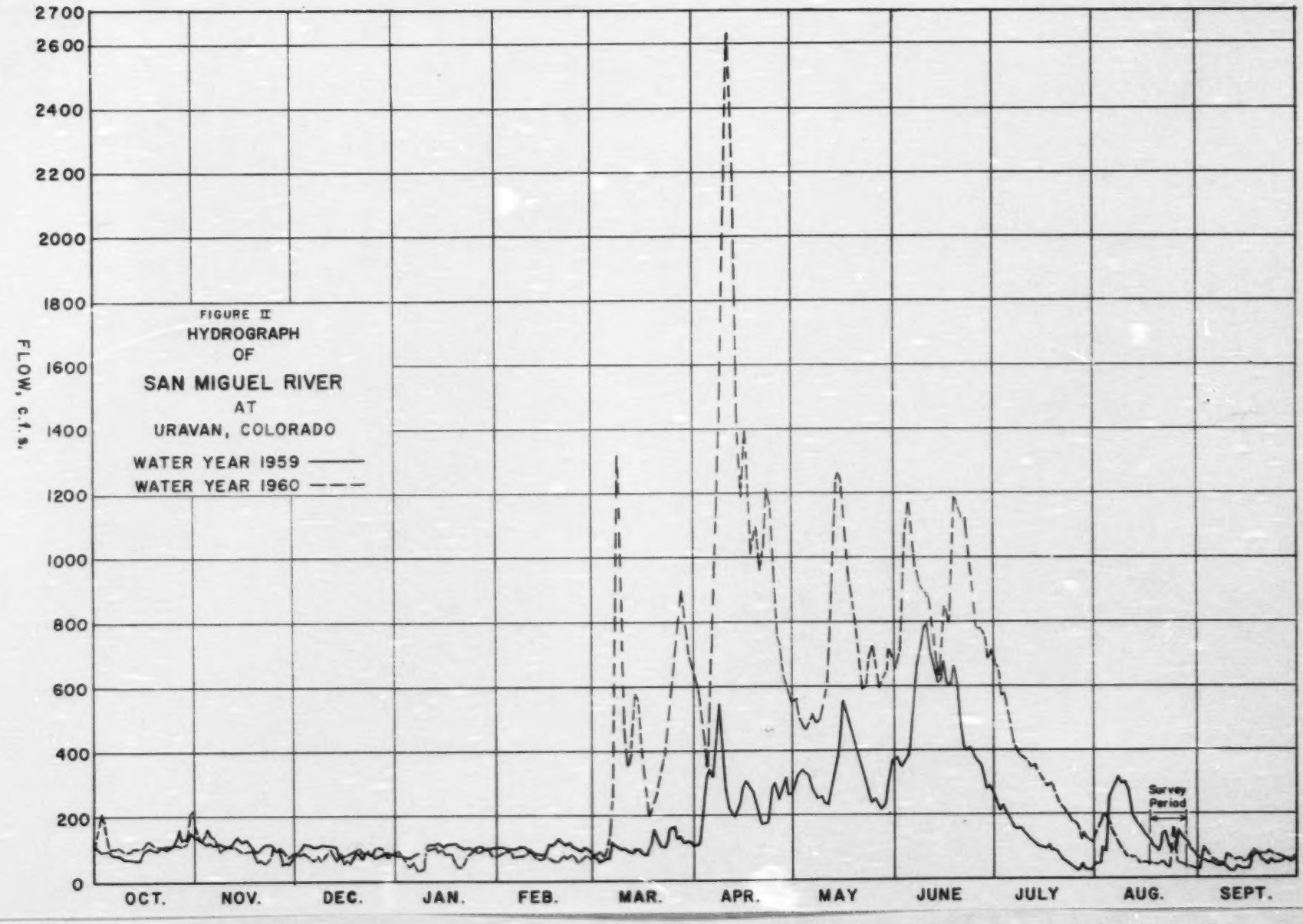
FIGURE II
HYDROGRAPH
OF
SAN MIGUEL RIVER
AT
URAVAN, COLORADO
WATER YEAR 1959
WATER YEAR 1960
FLOW, c.f.s.
2700
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
OCT.
NOV.
DEC.
JAN.
FEB.
MAR.
APR.
MAY
JUNE
JULY
AUG.
SEPT.
Survey Period

Flows during the two cycles were lower in each case than the lowest mean discharge for August during the period of record. Flows in cycle II have a wider range than those of cycle I and are 80 to 90 percent of the lowest mean August discharge over the periods of record. August is usually a low flow month in this area as weather is warm and much water is used for irrigation upstream.

RESULTS AND DISCUSSION

Chemical

Chemical analyses were performed by the laboratory of the Field Operations Section, R. A. Taft Sanitary Engineering Center, Cincinnati, Ohio. Results are presented for the Slick Rock area in Table V and for the Uravan area, including the Dolores River below the mouth of the San Miguel River, in Table VI.

Dolores River - Slick Rock Area

Even in this period of low flow, sufficient dilution was provided by the Dolores River to reduce concentrations of some constituents in Burro Mine effluent and Slick Rock plant seepage to values within the limits of the Public Health Service Drinking Water Standards (3). This was true of selenium, arsenic, and iron in the mine effluent. According to present knowledge, selenium is toxic both to humans and some animals in low concentrations; in the Drinking Water Standards, a concentration of 0.01 mg/l is grounds for mandatory rejection of the source for public water supply. Selenium in the stream was below limits at all river sampling stations, but there is a danger of its being present in unsafe concentrations for direct consumption at low flows if there should be any large increase in concentration from either effluent. It may be pointed out that the probability of direct human consumption at such times is remote. There was an increase in average nitrate concentration from 0.14 to 2.5 mg/l as the river passed from above Slick Rock to below the upgrading plant. Sulfate and total dissolved solids concentrations were above limits recommended in the Drinking Water Standards at all river stations in the Slick Rock area. Sulfate values ranged from 680 to 3160 mg/l; total dissolved solids concentrations as measured ranged from 1940 to 2240 mg/l (TDS values not reported for all stations).

During cycle II, the concentrations of sodium and chloride in the Dolores River rose sharply between Slick Rock and the confluence of the Dolores and the San Miguel Rivers. Below Slick Rock plant, these concentrations were 400 and 93 mg/l respectively, whereas they were 5800 and 5100 mg/l just above the entry of the San Miguel River. This rise was even more marked during cycle I. A similar occurrence was noted in a set of grab samples taken by the U. S. Geological Survey in August 1947 (4). Sodium and chloride concentrations then at Slick Rock were 53 and

TABLE V

CHEMICAL ANALYSES, SLICK ROCK AREA[a]

	Cycle	US-1 Dolores R. above Slick Rock	US-2 Dolores R. below Burro Mine above Slick Rock plant	US-3 Dolores R. just below Slick Rock Plant	US-4 Burro Mine effluent	US-5 Slick Rock plant seepage	US-6 Dolores R. 1/4 mi. above mouth of San Miguel River
pH	I	7.6	7.9	7.7	8.4	7.6	8.0
	II	7.8	7.6	7.6	8.7	7.5	7.5
Total alk. as $CaCO_3$	I	120	110	110	500	350	140
	II	110	100	100	540	390	110
Total hardness[b]	I	780	800	2200	75	4660	2360
	II	-	760	1960	47	4670	1270
Na	I	440	330	460	720	-	15400
	II	490	360	400	660	350	5800
Cl	I	370	160	84	72	140	13400
	II	400	160	93	68	180	5100
SO_4	I	680	920	2750	740	3950	1230
	II	890	970	3160	710	3950	740
Mn	I	<0.15	-	-	0.15	22	0.18
	II	0.20	0.20	0.50	0.20	23	0.14
Fe	I	0.08	0.10	0.08	0.38	0.40	0.08
	II	0.08	0.08	0.07	0.28	0.40	0.06
As	I	<0.01	0.01	<0.01	0.18	<0.01	<0.01
	II	<0.01	<0.01	<0.01	0.16	<0.01	<0.01
Se	I	<0.001	<0.001	0.008	0.070	0.080	0.004
	II	0.004	0.005	0.005	0.020	0.060	0.003
V	I	<0.005	0.035	0.10	0.74	0.12	0.010
	II	0.006	0.070	0.070	0.35	-	0.020
Cu	I	0.008	0.007	0.007	0.035	1.2	0.009
	II	0.015	0.008	0.017	0.015	7.4	0.010
F	I	0.49	0.62	0.78	0.70	-	1.1
	II	0.41	0.53	0.71	2.3	1.4	0.76
NO_3 as N	I	0.16	0.12	1.4	4.4	8.9	-
	II	0.12	0.12	3.6	5.6	13.	0.4
Total dissolved solids	I	2240	-	5350	1940	-	-
	II	-	-	-	-	-	-

(a) All analyses except pH in mg/l

(b) As $CaCO_3$

TABLE VI
CHEMICAL ANALYSES, URAVAN TO GATEWAY(a)

	Cycle	US-7 San Miguel R. above Uravan	US-8 Red cake tails, Uravan mill	US-9 Plant 5 effluent, Uravan mill	US-10 Yellow cake press filtrate, Uravan mill	US-11 Ditch drainage, Uravan mill	US-12 San Miguel R. 1.6 mi. below Uravan	US-13 San Miguel R. just above mouth	US-14 Dolores R. 12 mi. below confluence	US-15 Dolores R. at Gateway, Colo.
pH	I	7.9	2.3	3.2	7.6	8.0	7.6	7.7	7.7	7.8
	II	7.6	2.7	3.4	8.0	8.1	7.7	7.6	7.6	7.8
Total alk. as $CaCO_3$	I	120	-	-	130	210	92	82	92	92
	II	130	-	-	240	200	130	98	110	92
Total hardness (b)	I	630	210	13,000	2,920	1,600	830	850	800	760
	II	710	380	11,000	2,850	1,400	850	900	820	850
Na	I	56	30,000	2,600	23,800	300	260	250	620	660
	II	84	15,000	1,100	13,600	150	250	290	660	1,080
Cl	I	10	160	2,300	11,700	62	130	120	500	500
	II	14	160	1,500	11,300	82	140	120	570	1,050
SO_4	I	550	3,920	4,090	4,170	1,540	1,330	1,330	1,000	780
	II	640	3,930	4,010	3,940	1,170	1,260	1,310	990	900
Mn	I	0.15	-	-	5.1	0.32	1.28	0.72	0.16	<0.15
	II	<0.15	0.36	27.0	4.8	<0.15	0.48	0.32	0.38	<0.15
Fe	I	0.07	3.00	600	9.42	1.42	0.08	0.07	0.06	0.08
	II	0.08	3.42	544	6.04	0.64	0.08	0.08	0.08	0.11
As	I	<0.01	0.32	0.32	0.04	0.07	<0.01	<0.01	<0.01	<0.01
	II	<0.01	0.19	0.07	0.01	0.01	<0.01	<0.01	<0.01	<0.01
Se	I	0.002	<0.001	-	0.015	0.005	0.006	0.004	0.005	0.003
	II	0.004	0.020	0.020	0.18	0.020	0.006	0.004	0.004	0.003
V	I	<0.005	82.5	0.05	1.12	0.69	0.015	<0.005	0.015	0.055
	II	0.005	99.8	0.005	1.01	0.86	0.04	0.070	0.025	0.03
Cu	I	0.006	0.075	6.12	0.112	0.020	0.018	0.015	0.011	0.009
	II	0.009	0.090	3.72	0.105	0.018	0.009	0.011	0.010	0.007
F	I	0.62	4.92	-	1.71	1.11	0.62	0.90	0.62	0.57
	II	0.59	4.44	0.94	1.11	0.62	0.53	0.65	0.62	0.49
NO_3 as N	I	0.12	0.32	-	-	0.72	0.42	0.70	1.1	1.8
	II	0.16	0.20	-	-	2.3	0.30	0.34	0.70	-
Total dissolved solids	I	1030	61,000	71,000	75,000	2,940	2,320	-	3,020	-
	II	-	-	-	-	-	-	-	-	-

(a) All analyses except pH in mg/l
(b) As $CaCO_3$

TABLE VI
CHEMICAL ANALYSES, URAVAN TO GATEWAY(a)

	Cycle	US-7 San Miguel R. above Uravan	US-8 Red cake tails, Uravan mill	US-9 Plant 5 effluent, Uravan mill	US-10 Yellow cake press filtrate, Uravan mill	US-11 Ditch drainage, Uravan mill	US-12 San Miguel R. 1.6 mi. below Uravan	US-13 San Miguel R. just above mouth	US-14 Dolores R. 12 mi. below confluence	US-15 Dolores R. at Gateway, Colo.
pH	I	7.9	2.3	3.2	7.6	8.0	7.6	7.7	7.7	7.8
	II	7.6	2.7	3.4	8.0	8.1	7.7	7.6	7.6	7.8
Total alk. as $CaCO_3$	I	120	-	-	130	210	92	82	92	92
	II	130	-	-	240	200	130	98	110	92
Total hardness (b)	I	630	210	13,000	2,920	1,600	830	850	800	760
	II	710	380	11,000	2,850	1,400	850	900	820	850
Na	I	56	30,000	2,600	23,800	300	260	250	620	660
	II	84	15,000	1,100	13,600	150	250	290	660	1,080
Cl	I	10	160	2,300	11,700	62	130	120	500	500
	II	14	160	1,500	11,300	82	140	120	570	1,050
SO_4	I	550	3,920	4,090	4,170	1,540	1,330	1,330	1,000	780
	II	640	3,930	4,010	3,940	1,170	1,260	1,310	990	900
Mn	I	0.15	-	-	5.1	0.32	1.28	0.72	0.16	<0.15
	II	<0.15	0.36	27.0	4.8	<0.15	0.48	0.32	0.38	<0.15
Fe	I	0.07	3.00	600	9.42	1.42	0.08	0.07	0.06	0.08
	II	0.08	3.42	544	6.04	0.64	0.08	0.08	0.08	0.11
As	I	<0.01	0.32	0.32	0.04	0.07	<0.01	<0.01	<0.01	<0.01
	II	<0.01	0.19	0.07	0.01	0.01	<0.01	<0.01	<0.01	<0.01
Se	I	0.002	<0.001	-	0.015	0.005	0.006	0.004	0.005	0.003
	II	0.004	0.020	0.020	0.18	0.020	0.006	0.004	0.004	0.003
V	I	<0.005	82.5	0.05	1.12	0.69	0.015	<0.005	0.015	0.055
	II	0.005	99.8	0.005	1.01	0.86	0.04	0.070	0.025	0.03
Cu	I	0.006	0.075	6.12	0.112	0.020	0.018	0.015	0.011	0.009
	II	0.009	0.090	3.72	0.105	0.018	0.009	0.011	0.010	0.007
F	I	0.62	4.92	-	1.71	1.11	0.62	0.90	0.62	0.57
	II	0.59	4.44	0.94	1.11	0.62	0.53	0.65	0.62	0.49
NO_3 as N	I	0.12	0.32	-	-	0.72	0.42	0.70	1.1	1.8
	II	0.16	0.20	-	-	2.3	0.30	0.34	0.70	-
Total dissolved solids	I	1030	61,000	71,000	75,000	2,940	2,320	-	3,020	-
	II	-	-	-	-	-	-	-	-	-

(a) All analyses except pH in mg/l
(b) As $CaCO_3$

and 55 mg/l respectively, while they were 2350 and 3520 mg/l just above the entry of the San Miguel River. Uravan mill takes brine solution for its ion exchange process from a well northeast of Bedrock, on the north side of Paradox Valley, east of the Dolores River. Several wells have been drilled in this same general area recently to furnish brine for oil field use in southeastern Utah. From these considerations, it appears likely that the noted increases in sodium and chloride concentrations are probably due to natural causes.

The useful potential of this stream is decreased greatly by its high dissolved solids, sulfate, sodium, and, below Bedrock, chloride contents. This is attested by the fact that local farmers choose not to use river water for irrigation when the flow is low unless there is no other alternative. Any industry locating on the river in the area from Slick Rock to the entry of the San Miguel River and needing soft water might be put to considerable expense if the Dolores River were the only available source of supply. Primary causes for the above-mentioned high concentrations of most of these constituents are probably upstream soil types and uses (5). Notice is taken of the sulfate contribution from Slick Rock plant seepage (about 2200 pounds/day, based on river flows) as another cause of high sulfate concentration downstream from the plant.

San Miguel River - Uravan Area

As mentioned before, it is assumed that flows of the San Miguel River are essentially equal above and below the Uravan mill. Table VII gives estimated annual average effluent flow rates with some characteristics of each stream (10).

TABLE VII
URAVAN EFFLUENT STREAM CHARACTERISTICS

Station	Name	Flow, cfs	Major Dissolved Materials
US-8	Red Cake Tailings Liquor	0.16	H_2SO_4, Na_2SO_4
US-9	Plant 5 Pont Overflow	0.56	$(NH_4)_2SO_4$, $BaCO_3$ or $BaCl_2$
US-10	Yellowcake Tailings Liquor	0.16	NaCl, Na_2SO_4
US-11	Ditch Drainage	0.11	- -

Redcake tailing liquor and Plant 5 overflow are quite acid as they enter the San Miguel River. Two factors apparently combine to reduce the effect of these acid streams on the river. One is dilution; the acid streams were diluted 64:1 in the river on the average over the survey. Barium carbonate or barium chloride was being added to the Plant 5 overflow during the survey. Unreacted barium salts which did not settle in the tailings ponds may have helped neutralize some of the effluent acidity as the various effluents were mixed with each other and water in the river.

River water both upstream and downstream from Uravan is very hard, with typical concentrations ranging from 630 to 900 mg/l as $CaCO_3$. Water of this hardness generally requires softening before industrial use. The Uravan mill has a softening plant for boiler feed water.

Passing along the river from above Uravan to 1.6 miles below town, there were three places where chemical measurements were made. One is above town, the second may be visualized as the sum total of all chemical discharges from the mill and the third is below town. With this consideration in mind, one would expect that the measurement below Uravan would reflect both of the other two. In terms of a weight of some specific chemical, the weight measured passing a point upstream from Uravan plus the weight of chemical added in all mill discharges would be equal to the weight measured passing a point downstream from Uravan.

There are two very striking exceptions to the pattern just described. Neither the iron nor the vanadium analyses of samples collected 1.6 miles downstream from Uravan reflects directly the amounts of these chemicals in solution upstream from town and added in the mill discharge. In the case of iron, 1800 pounds/day were added to the river by the effluents and ditch drainage from Uravan during cycle I. At the station 1.6 miles downstream from Uravan, 17 pounds/day of dissolved iron passed during cycle I, while 15 pounds/day of dissolved iron discharged by the mill during cycle II were not found in solution 1.6 river miles below the mill. The largest part of this iron is discharged in Plant 5 overflow. The red-brown color of the river below Plant 5 pond effluent entry has been mentioned and is probably due largely to formation of colloidal and floc particles of hydrous ferric oxide. Some floc is formed in the ponds through which Plant 5 overflow passes on its way to the river; floc particles probably continue forming, growing and settling as the Plant 5 effluent mixes with the river until nearly all of the iron has settled out or gone into suspension by the time the river reaches the downstream sampling station.

In a similar manner, it was found that more vanadium was added to the river than was reflected in dissolved vanadium analyses of samples

collected downstream from the mill. Better than 98% of all the vanadium in the mill effluent during the survey was added in the waste redcake tailings liquor. This is an acid effluent stream, and it carries the vanadium to the river in the form of a soluble ion. Probably because of dilution and neutralizing action of discharged barium salts, the river pH was found to be very nearly the same, just above neutral, both above the mill and 1.6 miles downstream from the mill. As the vanadium ions, in a soluble form in the acid effluent, come in contact with water in which the pH is changing from acid toward neutrality, they change from a soluble form to an insoluble one. Most of the vanadium precipitates out or goes into suspension in this short stretch of river; this action may be speeded by interaction with iron floc particles. Of about 72 pounds/day of vanadium added to the river during cycle I, better than 68 pounds/day were not found dissolved at the end of this 1.6 mile length of river channel. During cycle II, this was true of some 77 pounds/day out of some 87 pounds/day added.

Based on effluent flows, the mill contributed an average of 16,600 pounds per day of sulfate to the river. The flow information which resulted in this average was given in the form of an annual average. No measurements of effluent flow rate were made during the survey. Based on stream flows, the San Miguel River picked up some 170,000 pounds of sulfate per day between the sampling points just above and below Uravan. No means has been found to reconcile this difference at the present time.

The variation in sodium values at Stations US-8 and US-10 appears large when it is expressed in mg/l. For instance, at station US-8 during cycle I, the sodium concentration in the composite sample was 30,000 mg/l, whereas it was 15,000 mg/l during cycle II. However, when one considers these values as percentages of a component in a waste stream, the variation is not undue (3.0 vs. 1.5%). Sodium concentrations are raised in the San Miguel River, on the average, by a factor of about four due to the entry of effluent streams from the mill.

Chloride concentration in the San Miguel River rose by about a factor of ten as the river passed Uravan, but the level of chlorides above Uravan was very low (about 10 mg/l). A much greater change in chloride concentration is presumably caused by natural causes related to the Dolores River. Chloride concentration in the Dolores River has been mentioned as changing from 93 to 5100 mg/l during cycle II from below Slick Rock to the mouth of the San Miguel River and the change seems to have been attributable to natural causes. When the smaller flow and higher chloride concentration of the Dolores River were mixed with the larger flow

and lower chloride concentration of the San Miguel River, an arithmetic average of 415 mg/l rise was noted in the chloride level of the combined stream (Station US-14) as compared to the chloride level of the San Miguel River before mixing. By contrast, the arithmetic average rise of chloride concentration in the San Miguel River as it passed Uravan was 123 mg/l.

Sodium and chloride balances made around the confluence of the Dolores and San Miguel Rivers gave excellent agreement for cycle I. For example, a total of 106,400 pounds/day of chlorides were found above the confluence (Stations US-6 and US-13), while 110,400 pounds/day were found below the confluence. This agreement within five percent tends to show the consistency of the respective laboratory analyses.

On the other hand, two considerations apparently affect the striking of a similar material balance around the confluence during cycle II. Rain during the second cycle resulted in a wide range of flow at Station US-6, as seen in Table III. Using the average flow given there of 23 cfs, the resulting material balance for chloride shows 666,000 pounds/day above the confluence against 196,000 pounds/day below as measured at Station US-14. An attempt was made to reconcile this difference by assuming the median flow for Station US-6, cycle II, to have been more representative of flow conditions during the sampling period. This attempt gave a value of 296,000 pounds/day of chlorides above the confluence compared to the 196,000 pounds/day below. This is not a satisfactory agreement. It is felt that neither the sample taken nor the flow averages used is truly representative of river conditions caused by the intense rain. The other factor that may affect these results is not seen directly in these figures themselves. Station US-14 is located twelve miles downriver from the confluence of the Dolores and San Miguel. It seems likely that various chemical constituents could be leached from the soil and carried away in the runoff from a heavy rain, thus affecting the concentration measured in a composite sample of the kind that was taken from the river during this survey.

Here, as in the Slick Rock area (Dolores River), all sulfate and total dissolved solids concentrations in river samples were above recommended limits in the U. S. Public Health Service Drinking Water Standards.

Radiological

Most of the radium-226 analyses were performed by a private laboratory; the remaining radium-226 and all the uranium analyses were done by Colorado River Basin Project personnel at the Public Health Service Occupational Health Field Station in Salt Lake City. Gross radioactivity analyses were carried out by the Field Operations Section, Robert A. Taft Sanitary Engineering Center.

Data from radium-226 and uranium analyses of stream and effluent samples are presented in Tables VIII and IX. Generally, levels of both radium-226 and uranium are higher in the samples taken during cycle II than in those taken during cycle I. For instance, in the San Miguel River above Uravan, the dissolved radium concentrations were 1.6 and 0.3 μμg/l for cycle II and cycle I respectively; corresponding dissolved uranium concentrations were 7.9 and 6.5 μg/l. Calculated ratios of dissolved radium-226, cycle II, to dissolved radium-226, cycle I, in the stream samples ranged, with one exception, from 1.1:1 to 1.6:1. Corresponding values for dissolved

uranium ranged from 1.1:1 to 1.7:1. As discussed before, rain fell in the survey area at the beginning of cycle II. Stream flows rose as a consequence of the rain and the turbidity of the rivers also increased. The increase in turbidity at any one point was due partly to natural runoff and partly to resuspension of sediment which had settled on the stream bed above that point.

It is possible that radium-226 and uranium from upstream sources of radioactive contamination were redissolved during the period of high stream flow after having been previously associated with settled sediment in the upstream channel. This could have occurred in the following manner. During the previous low flow period, radium-226 and uranium from upstream sources which were associated with the suspended sediment in the river settled to the stream bed. When the stream flow rose rapidly, as was the case during the survey, the greater turbulence of swiftly moving water scoured the settled sediment from the channel bottom. There was much more intimate contact between the mass of resuspended sediment, its associated radioactivity, and the liquid phase than would be the case had there been no increase in stream flow. This more thorough contact between solids and water increased the chances for dissolution of the previously settled radium-226 and uranium, resulting in a corresponding increase of concentrations of these constituents in the stream. This phenomenon has been reported in other similar studies (1)(11).

Burro Mine effluent contained an arithmetic average of 47 μμg/l of radium-226 and raised the concentration of radium-226 in the Dolores River at its entry by at least a factor of six. The average radium-226 concentration in the Dolores River above the mine was $\leq$ 0.55 μμg/l; below the mine but above Slick Rock plant, it was 3.3 μμg/l. On the other hand, radium-226 levels in the Slick Rock plant seepage were essentially the same as in the Dolores River below the plant, just less than 1 μμg/l. The level of activity in the plant seepage may be accounted for by two factors: (1) In-plant leaching is carried out on the "sands" fraction of ore particles only. Since only a portion of the ore is leached, radium-226 levels in the effluent to the tailings pile would be lower than if all ore fed to the plant had been leached; (2) There is apparently a reduction in radium-226 content of the mill effluent liquor due to an ion exchange or similar mechanism occurring in the soil through which the liquor passes before reaching the river as seepage.

Handbook 69 of the National Bureau of Standards (6) gives the maximum 168 hour occupational exposure limits to radium-226 and uranium in water as 10^{-7} and 2×10^{-4} μc/cc respectively. The International Commission on Radiological Protection recommends (7) a maximum of 1/30 of the continuous occupational exposure, or 3.3 μμg/l for radium-226 and 20,000 μg/l for uranium for lifetime consumption by the general population. In the U. S. Public Health Service Drinking Water Standards, an annual average of greater than 3.0 μμg/l of dissolved radium-226 in water constitutes ground for rejection of the supply as a source of drinking water. At the low flows encountered during this survey, concentrations of radium-226 in the Dolores River were at or above these levels in three locations in the survey area; below Burro Mine (average of 3.3 μμg/l), above the confluence of the San Miguel River (3.0 and 3.8 μμg/l), and at Gateway (arithmetic average of 5.5 μμg/l). The effects of radium-226 levels above 3.0 μμg/l have not been evaluated for the inhabitants of Slick Rock who may use Dolores River water for domestic purposes. Neither have the effects caused by irrigation of crops in this area

TABLE VIII
DISSOLVED RADIUM-226 AND URANIUM, SLICK ROCK AREA

Station		Dissolved Radium-226 µµg/l Cycle I	Dissolved Radium-226 µµg/l Cycle II	Dissolved Uranium µg/l Cycle I	Dissolved Uranium µg/l Cycle II
US-1	Dolores R. above Slick Rock	0.1	≤ 1	6.5	7.7
US-2	Dolores R. below Burro Mine, above Slick Rock plant	2.6	4.0	170	290
US-3	Dolores R. just below Slick Rock plant	0.8	1.0	55	61
US-4	Burro Mine effluent	55	39	2500	3200
US-5	Slick Rock plant seepage	0.9	≤ 1	92	100
US-6	Dolores R. 1/4 mi. above mouth of San Miguel River	3.0	3.8	19	14

TABLE IX
DISSOLVED RADIUM-226 AND URANIUM, URAVAN TO GATEWAY

Station		Dissolved Radium-226 µµg/l Cycle I	Dissolved Radium-226 µµg/l Cycle II	Dissolved Uranium µg/l Cycle I	Dissolved Uranium µg/l Cycle II
US-7	San Miguel R. above Uravan	0.3	1.6	6.5	7.9
US-8	Red cake tails, Uravan mill	2.0	18	3100	1100
US-9	Plant 5 effluent, Uravan mill	≤1	≤1	7000	4400
US-10	Yellow cake press filtrate, Uravan mill	14	11	4300	2100
US-11	Ditch drainage, Uravan mill	19	25	2300	1900
US-12	San Miguel R. 1.6 mi. below Uravan	2.3	2.5	77	96
US-13	San Miguel R. just above mouth	1.7	2.3	78	88
US-14	Dolores R. 12 mi. below confluence	3.5	1.1	61	74
US-15	Dolores R. at Gateway, Colo.	4.3	6.7	45	74
M - 2	Dolores R. just above mouth (Data from ref. 2)	4.0	3.8	47	47

with Dolores River water containing concentrations of radium-226 greater than 3.0 μμg/l been evaluated. Waters of the Upper Colorado River Basin of natural background levels generally have radium-226 concentrations of less than 1 μμg/l. Arithmetic averages of radium-226 concentration were less than 1 μμg/l in the Dolores River above and below Slick Rock and in the San Miguel River above Uravan.

Dissolved uranium levels in stream samples were nowhere greater than 300 μg/l, though the majority of values in the effluent samples ranged from 1000 to 7000 μg/l. Uranium concentrations in Slick Rock plant seepage were much lower than this range, on the order of 100 μg/l, probably for reasons similar to those discussed above in relation to the radium-226 level of this seepage.

The increase in radium-226 concentration in the Dolores River from less than 1 μμg/l below Slick Rock to greater than 3 μμg/l just above the mouth of the San Miguel River may be due to the entry of mine seepage or inflows from other natural drainage. The Dolores flows through an area of many uranium and vanadium mines between Slick Rock and the mouth of the San Miguel and its major tributary in this reach, LaSal Creek, also drains an area of numerous mines. Radium-226 levels in the San Miguel River just above the confluence were lower than in the Dolores, so the noted increase was probably not due to water from the San Miguel, with its higher flow, backing up into the channel of the Dolores. Dissolved radium-226 levels also increased between the confluence and Gateway, possibly due to the reasons noted above.

At Uravan mill, radium-226 levels in Plant 5 effluent were much lower than those in any of the other streams coming from the mill property. This stream was receiving barium treatment during the survey, designed to remove radium by coprecipitation with barium sulfate. Radium-226 and uranium concentrations in the ditch drainage sampled at Station US-11 were comparable to those being discharged in the process wastes, suggesting that at least part of the ditch drainage is seepage from the acid leach tailings ponds located atop the mesa above the mill. The ditch drainage and yellow cake tailings liquor are discharged to the San Miguel River having concentrations of radium-226 greater than 3 μμg/l. However, the arithmetic average of radium-226 concentrations in the San Miguel 1.6 miles below Uravan during the low flows encountered in the survey was 2.4 μg/l.

Table X presents weight flow rates of dissolved radium-226 and uranium past sampling points. For stations where a stream flow rate was not measured, there are no results in this table. As mentioned in the section on chemical results, other factors enter into consideration of weight flow rates. Waste flow figures from the Uravan mill were given as annual averages and may not be representative of flow conditions at the time of the survey, hence the weight rates reported here may not be representative of actual conditions during the survey. Rain during the second compositing cycle caused a large variation in flow at Station US-6, the Dolores River just above the mouth of the San Miguel River. It was impossible to insure that the portions of the composite sample taken there during the second cycle were taken in proportion to flow. For this reason, the sample is not truly representative of river conditions. Nor is the arithmetic average flow during this period a representative one; in an attempt to secure a more accurate representation of river conditions, the

TABLE X

WEIGHT FLOW RATES OF DISSOLVED RADIUM-226 AND URANIUM

Station	Location	µg/day of radium-226		gm/day of uranium	
		Cycle I	Cycle II	Cycle I	Cycle II
US-1	Dolores River above Slick Rock	0.01	≤0.07	0.8	0.6
US-2	Dolores River below Burro Mine, above Slick Rock plant	(1)	(1)	(1)	(1)
US-3	Dolores River just below Slick Rock plant	0.4	0.5	27	33
US-4	Burro Mine effluent	(1)	(1)	(1)	(1)
US-5	Slick Rock plant seepage	(1)	(1)	(1)	(1)
US-6	Dolores River 1/4 mi. above mouth of San Miguel River	8.1	89(2)	51	330(2)
US-7	San Miguel River above Uravan	29	210	620	1000
US-8	Red cake tails, Uravan mill	0.8	7.0	1200	430
US-9	Plant 5 effluent, Uravan mill	≤1.4	≤1.4	9600	6000
US-10	Yellow cake press filtrate, Uravan mill	5.5	4.3	1700	820
US-11	Ditch drainage, Uravan mill	5.1	6.7	620	510
US-12	San Miguel River 1.6 mi. below Uravan	220	330	7400	12000
US-13	San Miguel River just above mouth	170	320	6000	10000
US-14	Dolores River, 12 mi. below confluence	330	170	5800	7400
US-15	Dolores River at Gateway, Colorado	410	1000	4500	7400
M - 2	Dolores River just above mouth	360	550	4200	6800

(1) Flow not measured at this station
(2) Based on median flow measurement

median discharge was used to calculate weight flow rates in Table X for Station US-6, Cycle II.

With these considerations in mind, examination of Table X reveals several interesting occurrences. There is a gradual buildup of dissolved radium-226 and uranium between the point sampled farthest upstream on the Dolores River and the point on the Dolores just above the mouth of the San Miguel. There is a similar increase on the San Miguel River from the point just upstream from Uravan to the sample point 1.6 miles downstream from Uravan. On the basis of the figures in Table X, it is not possible to attribute all the noted increase in the San Miguel River to waste discharges from Uravan mill. For instance, in Cycle I when stream flows were relatively constant, there was an increase of 190 µg/day of radium-226 in the river as it passed Uravan mill, based on streamflow calculations. Based on estimates of waste discharge, the average contribution of radium-226 from the mill was a maximum of 12.8 µg/day. This is similar to the results having to do with sulfate in the mill discharge as noted on page 14. No present means has been found to reconcile this discrepancy.

As done above for sodium and chloride, an attempt was made to strike material balances for radium-226 and uranium around the confluence of the two rivers. The radium-226 balances do not agree within themselves for either cycle. During Cycle I, the average inflow to the confluence (Stations US-6 and US-13) was 880 µg/day, the average outflow at Station US-14 was 1670 µg/day. For Cycle II, the corresponding inflow and outflow were 2660 µg/day and 1210 µg/day. These differences remain to be explained.

The uranium balance for Cycle I showed good agreement, with 3 percent less outflow than inflow. Agreement on the second cycle balance, however, was only within 45 percent; it is felt that the weight outflow (Station US-14, Cycle II) is not completely consistent with corresponding weight flow rates calculated for sampling stations farther down the Dolores River.

If the flow of the Dolores River above the mouth of the San Miguel River is disregarded temporarily, it is seen that there was a steady reduction in the weight of dissolved uranium passing each sampling point beginning just below Uravan mill (12,420 gm/day, Cycle I) and continuing to the mouth of the Dolores River (6770 gm/day, Cycle I). This holds with consistency for both cycles. In each case, the weight of uranium remaining dissolved at the mouth of the Dolores River was about 55 percent of the weight of dissolved uranium passing the sampling point just below Uravan mill. There was a reduction from the weight of dissolved radium-226 passing just below Uravan to the similar weight at the mouth of the San Miguel River. This was probably due to some interaction of radium-226 with the precipitation process occurring in this reach of the river. The steady decrease in the weight of dissolved uranium passing consecutive sampling points downstream from Uravan mill is not noted with the remainder of the stations for dissolved radium-226. The weight of dissolved radium-226 passing downstream fluctuates from station to station on the main stem of the Dolores River below the mouth of the San Miguel; there is no consistent trend. However, in each cycle, the weight of dissolved radium-226 passing the mouth of the Dolores River was 65 percent higher than the corresponding weight passing the sampling station 1.6 miles below Uravan mill.

Partial causes for this may be inflow of the Dolores River at the confluence of the Dolores and San Miguel Rivers and seepage from mines along the Dolores River, both above and below Gateway; and in Cycle II, natural runoff during the period of rain. Results have not yet been reported from sediment samples taken recently in the stretch of the Dolores River below Gateway to clarify the second hypothesis raised above.

From the foregoing discussion, it is apparent that several questions unsolved by this survey will not be answered without further work.

Table XI presents data on radioactivity in sediments from sampling point located upstream of man-made sources of contamination (8). These data indicate generally the level of radioactivity to be found in naturally occurring Upper Colorado River Basin sediments. Table XII presents similar data obtained in the survey area for comparison. Eighteen of 20 samples in this survey area contained higher concentrations of radium-226 than the average radium-226 concentrations in the background samples, i.e., 1.3 μg/gm of dry sediment.

TABLE XI
BACKGROUND LEVELS OF RADIOACTIVITY IN RIVER SEDIMENTS[a]

Location	Gross α	Gross β	Radium-226
Colorado River at Silt, Colorado	6.5	78	1.7
Yampa River at Juniper Springs, Colo.	4.0	50	<1.0
Green River near Dutch John, Utah	8.6	45	<1.0
San Juan River above Farmington, N.M.	5.3	21	0.9
Animas River above Durango, Colorado	11	29	1.3
Dolores River above Slick Rock, Colorado	14	43	2.2
San Miguel River above Naturita, Colorado	9.5	38	1.0
Tomichi Creek above Gunnison, Colorado	11	47	1.2
Gunnison River above Tomichi Creek	9.0	52	1.6

[a]All analyses in μμc/gm of dry sediment

As would be expected, the data show an increase in radioactivity immediately below uranium mills. Gross alpha and radium-226 concentrations rose gradually as the Dolores River passed from above to below Burro Mine to below the Slick Rock upgrading plant. Levels of these constituents just below Slick Rock were one and one-quarter to two times as high as those just above Slick Rock. Radioactivity levels in sediment taken just above Uravan were better than twice as high as the average corresponding levels in the background samples, reflecting the presence of a source of radioactivity upstream from Uravan.

TABLE XII
RADIOACTIVITY LEVELS IN RIVER SEDIMENTS, DOLORES AND SAN MIGUEL RIVERS(a)

Station	Location	Cycle I			Cycle II		
		Gross α	Gross β	Radium-226	Gross α	Gross β	Radium-226
US-1	Dolores River above Slick Rock	11	52	2.0	20	48	2.8
US-2	Dolores River below Burro Mine, above Slick Rock plant	9.0	42	2.7	21	63	3.4
US-3	Dolores River just below Slick Rock plant	21	55	4.2	32	62	3.8
US-6	Dolores River 1/4 mi. above mouth of San Miguel River	5.8	34	≤1	16	64	11
US-7	San Miguel River above Uravan	29	40	5.5	24	82	2.9
US-12	San Miguel River 1.6 mi. below Uravan	260	270	29	43	105	6.0
US-13	San Miguel River just above mouth	210	160	33	40	72	4.9
US-14	Dolores River, 12 mi. below confluence	59	97	4.3	36	104	5.2
US-15	Dolores River at Gateway, Colorado	8.4	44	1.6	5.2	23.2	1.2
M - 2	Dolores River just above mouth	53	59	8.9	41	87	7.5

(a) All analyses in μμc/gm of dry sediment

Second cycle sediment samples on the San Miguel River below Uravan show about one-fifth to one-sixth the general level of radioactivity of the first cycle samples. This is probably due to the second cycle rain with its increased stream flows and turbulence scouring the channel bottom to some extent. This set of samples was taken near the end of the cycle, when stream flows had returned to the levels found during the dry first cycle. First cycle samples show radium-226 and gross alpha concentrations to be 29 μμg/gm and 260 μμc/gm respectively, 1.6 miles below Uravan. These data and those at the mouth of the San Miguel are indicative of the precipitation process occurring along this reach of the river, as was seen in the reduction in weights of dissolved radium-226 and uranium mentioned above.

Data for Station M-2, just above the mouth of the Dolores River, may indicate the accumulation of radioactivity from all sources within the Dolores-San Miguel River system as well as the entry of contaminants from sources between Gateway and the mouth of the Dolores River. Concentrations of gross alpha radioactivity and radium-226 in sediment were 5 to 6 times as high at the mouth of the Dolores River as at Gateway.

Biological

Bottom Fauna Studies

Stations B-1, B-2, and B-3, all on the Dolores River above the mouth of the San Miguel, yielded few organisms per square yard. Midges (Tendipedidae), beetles, water bugs, and an aquatic worm were the kinds of organisms obtained. All of these are tolerant to poor quality water.

Station B-6, on the San Miguel River below the Naturita mill (closed), some 13 miles above Uravan, yielded a large number of organisms, including many which are not tolerant to poor quality water. There were 880 organisms in a square yard with nine species represented.

Both at the station 1.6 miles below Uravan and just above its mouth, the San Miguel yielded about the same variety of organisms as at the station above Uravan. However, there were considerably fewer organisms per unit area and fewer kinds that are tolerant to pollution. Though there was a distinct reduction in the number of organisms below Uravan, a significant number was found, indicating that the stream provided an environment supporting aquatic life in a limited way. Just below the confluence of the Dolores and San Miguel pollution-intolerant organisms were found in approximately twice the number and weight as on the San Miguel below Uravan. This showed an improvement in the environment for bottom fauna.

At the time of sampling at Station B-8 at Gateway, the Dolores River flowed rapidly over rocks but was warmer and more turbid than upstream. Bottom fauna were scarce, with only 15 found per square yard. The poor habitat at Gateway may be attributed to turbidity and temperature.

Table XIII lists the number of each kind of organism collected and showed their total number and weight.

TABLE XIII
BOTTOM FAUNA COLLECTIONS
FROM SAN MIGUEL AND DOLORES RIVERS

Station	B-1	B-2	B-3	B-4	B-5	B-6	B-7	B-8
Organisms								
Ephemeroptera								
Baetidae						2		
Plecoptera								
Perlodidae Isogeniae				3		73	11	6
Pteronarcidae Pteronarcella				2		70		
Perlidae				1		80		1
Trichoptera								
Psychomyiidae		4					1	
Hydropsychidae				218	6	587	61	78
Brachycentridae				54		63	4	15
Diptera								
Tendipedidae	11	12	1	18	8	1	68	28
Simulidae				4	6			
Rhagionidae						3	1	5
Tipulidae						1	2	
Ephydridae			3		1			
Deuterophlebiidae					1			
Megaloptera								
Corydalidae Corydalus cornutus				3	3			
Coleoptera								
Elmidae	2	11		3	1			1
Dytiscidae		3						
Hemiptera								
Naucoridae	6	5						
Veliidae (Rhagovelia obesa)					1		2	
Odonate								
Gomphidae ophiogomphus				1				2
Coenagrionidae								1
Annelida								
Lumbriculidae		1						
Number of species	3	6	2	10	9	9	8	9
Square yards sampled	1	1	2	1	2	1	1	1
Number of organisms per square yard	19	36	2	307	15	880	150	137
Weight of organisms (grams)	0.2	0.3	0.1	9.4	1.5	13.3	2.1	4.7
Weight of organisms per square yard	0.2	0.3	<0.1	9.4	.7	13.3	2.1	4.7

Bioassay Studies

The effluent samples for bioassay testing from the Uravan and Slick Rock areas were brought to the State fish hatchery at Durango, Colorado. Facilities were available there for exposing rainbow trout to various dilutions of the wastes under constant temperature conditions. Vessels with 2 liters of test solution were placed in hatchery troughs containing spring water at a temperature of 52°F. Small trout ranging from 2 to 2-1/2 inches in length were used as test fish. Water from the Animas River above Durango was used for dilution.

The fish were exposed to the test solutions for 72 hours, and the individuals surviving this exposure period were counted. A semilogarithmic plot of number surviving versus concentration of waste was made; from this the 72-hour Median Tolerance Limit concentration (TL_m) was derived. The 72-hour TL_m is the concentration of effluent in water which causes 50 percent mortality of the test fish upon exposure for 72 hours. For each test series, control tests were run in which fish were placed in dilution water only.

Chemical analyses made on the test solutions included pH, alkalinity, hardness, and dissolved oxygen. Dissolved oxygen determinations were made at the start of tests and whenever there was reason to believe that the concentrations had lowered to endanger survival. Sufficient oxygen was maintained by limiting the number of fish in a vessel.

Tables XIV, XV, and XVI show the percentages of wastes in test solutions, the survival of fish, and chemical characteristics of these unfiltered waste samples. While the number of fish in any one sample is not large, it is felt that measurements made on any one group tend to be representative of the response of test fish in the particular concentration. This is particularly true since most test groups showed either all survivals or all deaths. It may therefore be considered that these data give a reasonable representation of the toxicity to test fish of the various waste streams.

Wastes from Burro Mine were not toxic to fish. These wastes had considerable turbidity due to suspended gray clay, and the pH was greater than that of the receiving stream. Slick Rock plant seepage was toxic with 72-hour median tolerance limits ranging from 1.5 to 2.4 percent.

The main waste stream at Uravan, uranium and vanadium stripped liquor had TL_m values ranging from 0.42 to 0.75 percent. Toxicity of the red cake tails effluent was not as great, with a TL_m range of 4.2 to 4.6 percent. Yellow cake tails effluent had a TL_m of 2.4 percent. Seepage from the acid leach tailings ponds was toxic to half the fish tested in a 100 percent concentration, but was not toxic to the fish tested in any lower concentration.

TABLE XIV
FISH SURVIVAL AND CHEMICAL
CHARACTERISTICS OF TEST SOLUTIONS - SLICK ROCK AREA

WASTE	% Waste	% Survival 72 Hr.	pH	Alkalinity mg/l	Hardness mg/l	Dissolved Oxygen, mg/l	No. of Fish
Burro Mine							
5-day composite	100	100	8.4	548	85	6.0	3
7-day composite	100	100	8.7	616	50	-	2
Mill Tailings Effluent							
5-day composite	1.0	100	7.6	212	295	5.4	5
	1.8	100	fish distressed and immobilized			-	5
	3.2	0	7.7	196	345	6.0	5
	5.6	0	7.4	216	495	5.6	5
	TL_m 2.4%						
7-day composite	1.0	100	7.5	212	270	6.6	4
	1.8	25	-	208	-	4.4	4
	3.2	0	7.4	212	360	5.3	5
	TL_m 1.5%						

TABLE XV
FISH SURVIVAL AND CHEMICAL
CHARACTERISTICS OF TEST SOLUTIONS - URAVAN AREA

WASTE	% Waste	% Survival 72 Hr.	pH	Alkalinity mg/l	Hardness mg/l	Dissolved Oxygen, mg/l	No. of Fish
Plant 5, Station US-9							
5-day composite	0.1	100	7.8	200	225	6.2-5.2	5
	0.18	100	7.4-7.8	-	-	6.2-4.6	5
	0.32	100	7.3-7.8	-	-	6.2-4.8	5
	0.56	0	7.0-7.8	192	290	5.8-6.4	5
	1.0	0	6.9	180	345	5.2	5
	TL_m 0.42%						
7-day composite	0.18	100	7.5	204	230	5.8-3.6	4
	0.32	100	-	-	-	-	4
		100	-	-	-	-	4
		0	-	-	-	6.6-3.6	4
	1.8	0	7.2	190	410	5.2	5
	3.2	0	7.8	162	560	4.7	5
	TL_m 0.75%						

TABLE XV (Continued)

WASTE	% Waste	% Survival 72 Hr.	pH	Alkalinity mg/l	Hardness mg/l	Dissolved Oxygen, mg/l	No. of Fish
Ditch Drainage Station US-11							
5-day composite	32	100	7.8	212	-	5.8	4
	56	100	7.6	220	-	6.2-5.2	4
7-day composite	56	100	7.9	220	985	-	2
	100	50	8.0	232	1455	-	2
TL_m 100%							
Red Cake Tails Station US-8							
5-day composite	1.8	100	7.0	172	205	7.0-3.6	5
	3.2	100	6.8	-	-	6.4-3.7	5
	5.6	0	6.5	92	-	6.2	5
	10	0	5.3	16	220	6.0	5
	18	0	3.2	-	225	5.6	5
TL_m 4.2%							
7-day composite	1.0	100	7.1	192	220	6.6-3.6	5
	1.8	100	7.0	-	-	-	5
	3.2	100	-	-	-	-	5
	5.6	25	6.6	-	-	6.4-3.2	4
	10.0	0	6.2	72	240	5.9-6.9	5
TL_m 4.6%							
Yellow Cake Press Filtrate Station US-10							
5-day composite	1.0	100	7.5	200	250	6.4	5
	1.8	100	-	-	-	-	5
	3.2	0	7.7	208	300	3.8	5
	5.6	0	7.8	192	365	6.8	5
TL_m 2.4%							
7-day composite	1.0	100	7.4	212	250	6.6	5
	1.8	100	-	-	-	-	5
	3.2	0	7.5	212	295	5.0	5
	5.6	0	7.6	214	360	6.0	5
TL_m 2.4%							

The degree of waste dilution required to prevent damage to fish life varies with the TL_m and flow rate of the waste. The required dilution flow rate may be calculated by the following formula (9):

$$\text{stream flow rate} = \frac{100-TL_m}{TL_m} \times \text{waste flow rate} \times \text{application factor}$$

where TL_m is expressed in percent. The application factor varies according to the characteristics of waste and receiving stream; it generally has values between three and ten. Its purpose is to provide sufficient water in excess of the TL_m concentration to dilute the waste to a harmless concentration for fish life.

TABLE XVI
FISH SURVIVAL AND CHEMICAL
CHARACTERISTICS OF DILUTION WATER

Starting Date	% Survival 72 Hr.	pH	Alkalinity mg/l	Hardness mg/l	Dissolved Oxygen, mg/l	No. of Fish
8-21-60	100	-	-	-	-	5
8-22-60	100	-	-	-	-	5
8-24-60	100	7.6	200	245	6.6	5
8-25-60	100	7.3	196	200	6.4	5
8-29-60	100	7.6	212	225	3.2	4

On the basis of this formula, the following estimates of the flow required for dilution are made, assuming the toxicity of ditch drainage to be negligible. The range of flow required for dilution of yellow cake tails waste to a concentration harmless to the test fish if adequate dissolved oxygen levels exist in the San Miguel River is ten to 37 cfs, depending on the choice of application factor. Likewise, the range of flows required for dilution of Plant 5 wastes is 222 to 1332 cfs and that for red cake tails dilution is 20 to 65 cfs. The range of flows thus required for dilution of all three streams is 252 to 1434 cfs. This summary range does not take into account any antagonistic or synergistic effects the wastes may have when combined.

Daily flow records have been published for the San Miguel River at Uravan for the period August 1, 1954 to September 30, 1959. Unpublished records are available for the period October 1, 1959 to September 30, 1960. Inspection of these data shows that, over the period of record, the flow of the San Miguel River at Uravan has been less that 250 cfs for 70 percent of the time. The maximum flow of record was 6,690 cfs, April 19, 1958. With these conditions of waste discharge and streamflow, it would be very difficult, if not impossible, to maintain an aquatic habitat suitable for desirable fish.

SUMMARY AND CONCLUSIONS

1. The larger portion of flow in the Dolores-San Miguel River system during this survey came from the San Miguel River. Flows during the second half of the survey, particularly in the Dolores River, were widely variable due to an intense local rain. The survey period was generally one of low flow when compared to the period of record.

2. Concentrations of sulfate and total dissolved solids in all stream samples were above limits recommended in the U. S. Public Health Service Drinking Water Standards. Water at all stream sampling stations was so hard as to require treatment if used for most domestic and some industrial uses.

3. A sharp increase in the concentration of sodium and chloride ions was noted in the Dolores River below Slick Rock. This is probably due to natural sources between Slick Rock and the confluence of the Dolores and San Miguel Rivers. The concentrations of both ions in the combined Dolores-San Miguel rose sharply over levels in the San Miguel River above its mouth. High salt concentrations reportedly interfere with irrigation use of the Dolores River in Colorado during low flow seasons.

4. The sum of weight of dissolved iron passing the sampling point above Uravan and weight of dissolved iron added in Uravan mill discharges far exceeded the weight of dissolved iron found in the San Miguel River below Uravan. This was also true for vanadium ions. It seems likely that precipitation of iron and vanadium was occurring to a large extent in the first mile and a half of the San Miguel below Uravan.

5. Rather marked discrepancies exist between the weights of sulfate and radium-226 discharges to the San Miguel River by Uravan mill calculated on the basis of stream flows and those calculated on the basis of effluent flows.

6. Attempts were made to strike material balances around the confluence of the Dolores and San Miguel Rivers. These balances resulted in generally good agreement during the dry weather of the first half of the survey. Agreement was generally not good during the half of the survey marked by rain. It was not possible to obtain a good balance for radium-226 around the confluence during either half of the survey, perhaps due to natural inflows or mining seepage between some of the sampling stations.

7. An increase in the concentration of dissolved radium-226 was noted in stream samples during the second half of the survey. This has been noted in other similar stream studies and was probably due to redissolution of radium-226 which had been previously associated with settled river sediments.

8. Concentrations of dissolved radium-226 in stream samples were at or above recommended limits of 3 μμg/l in the Dolores River below Burro Mine at Slick Rock, in the Dolores River just above the entry of the San Miguel River, in the Dolores River at Gateway, and in the Dolores River just above its mouth.

9. Concentrations of dissolved radium-226 were below 1 μμg/l in stream samples taken from the Dolores River above and immediately below Slick Rock, and from the San Miguel River above Uravan. Corresponding levels of dissolved radium-226 were found in the seepage from Slick Rock upgrading plant and in stripped ion exchange liquor from Uravan mill. This latter stream was being barium treated for radium removal during the survey.

10. Concentrations of dissolved uranium in stream samples were considerably less than recommended limits of 20,000 μg/l. The highest uranium concentrations in effluent streams were about 1/3 this level.

11. Much of the radium-226 in Uravan mill discharges is apparently precipitated in the San Miguel River within a very short distance downstream from the mill. This may occur through interaction with the precipitation noted in conclusion 4 above.

12. The weight of dissolved radium-226 in the river system generally increased in a downstream direction, possibly due to natural inflows and mine seepage or drainage in addition to the contributions made in mill discharges.

13. Background levels of radium-226 in sediment samples were about twice as high in the Dolores River above Slick Rock as in the San Miguel River above Naturita. Levels of radium-226 were higher in sediment samples taken immediately below uranium mills than in samples taken immediately above mills.

14. Levels of radium-226 in sediments taken at the mouth of the Dolores River may show an accumulation of radium-226 in sediment to be occurring between Gateway and the mouth of the Dolores River.

15. Bottom organisms were most prevalent on the San Miguel River above Uravan. This stream supports a limited population below Uravan mill. Dolores River quality is not favorable for the support of a good bottom fauna population in the immediate Slick Rock and Gateway areas.

16. Within the limitations of the bioassay toxicity test, and in view of the limited number of fish tested, the following conclusions may be drawn concerning the probable toxicity of the various effluents to fish in the Dolores-San Miguel River system:

a. Burro Mine drainage should not be toxic to rainbow trout. Slick Rock plant effluent is more toxic, having killed half the test fish in 72 hours in concentrations of about 2 percent.

b. Plant 5 waste should be the most toxic to fish of the wastes tested from Uravan; yellow cake press filtrate and red cake tails were less toxic to the test trout respectively. Ditch drainage from Uravan was essentially nontoxic to the test trout in 72 hours.

c. A minimum flow of 252 cfs in the San Miguel River is required (neglecting antagonism or synergism) for adequate dilution of wastes from Uravan mill so that the combination of wastes and river water not be toxic to young trout. Over the period of record, flow of the San Miguel River at Uravan has been less than 250 cfs 70 percent of the time.

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